03 Cell Cycle and Cell Division

01. INTRODUCTION

- Growth and reproduction are characteristics of cells, indeed of all living organisms.
- All cells reproduce by dividing into two, with each parental cell giving rise to two daughter cells each time they divide. These newly formed daughter cells can themselves grow and divide, giving rise to a new cell population that is formed by the growth and division of a single parental cell and its progeny.
- In other words, such cycles of growth and division allow a single cell to form a structure consisting of millions of cells.
- Term mitosis was proposed by **Flemming**. Mitosis produced genetically identical cells, which are also similar to mother cell.

CAUSE OF MITOSIS :

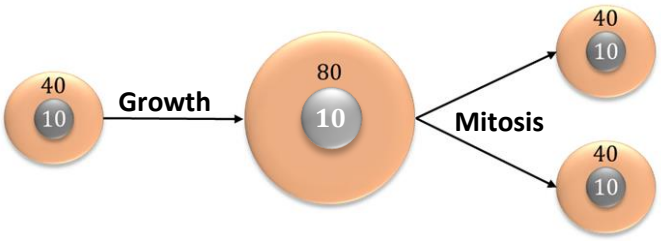
(A) **Kern plasm theory :** **Hertwig** proposed kern plasm theory. According to this theory mitosis occurs due to disturbance in Karyoplasmic Index (KI) or **Nucleocytoplasmic ratio** of cell.

Karyoplasmic Index: KI = $\frac{V_n}{V_c - V_n}$

Vn = Volume of nucleus

Vc = Volume of cell

Vc -Vn = Volume of cytoplasm



- Karyoplasmic Index of small cell is high as they have less cytoplasm. Nucleus efficiently controls the activity of cytoplasm in small cells.
- In a large cell, nucleus fails to control the activity of cytoplasm. To attain the control of nucleus on metabolism a large cell divides into two cells.

(B) **Surface-Volume Ratio :** Surface-volume ratio is also considered as a cause of cell division. When a cell grows in size its volumes increases more than its surface. So a stage will reach when the surface area of cell becomes insufficient to draw the materials from surrounding. At such critical stage, cell increases its surface volume ratio by division.

02. CELL CYCLE

- Cell division is a very important process in all living organisms. During the division of a cell, DNA replication and cell growth also take place. All these processes, i.e., cell division, DNA replication, and cell growth, hence, have to take place in a coordinated way to ensure correct division and formation of progeny cells containing intact **genomes**.
- The stages through which a cell passes from one division to the next is called the **cell cycle**. (The sequence of events by which a cell duplicates its genome, synthesises the other constituents of the cell and eventually divides into two daughter cells is termed **cell cycle**).
- Although cell growth (in terms of cytoplasmic increase) **usually is a continuous process**, DNA synthesis occurs only during one specific stage in the cell cycle.
- The replicated chromosomes (DNA) are then distributed to daughter nuclei by a **complex series of events** during cell division. These events are themselves **under genetic control**.

PHASES OF CELL CYCLE :

- **A typical eukaryotic cell cycle is illustrated by human cells in culture**. These cells divide once in approximately every **24 hours**. However, this duration of cell cycle can vary from organism to organism and also from cell type to cell type. **Yeast** for example, can progress through the cell cycle in only about **90 minutes**.
- The cell cycle is divided into two basic phases: Interphase & M-Phase (Mitosis phase).

NCERT Question :
What is the average cell cycle span for a mammalian cell?
Ans. The average cell cycle span for a mammalian cell is 24 hours.

INTERPHASE :

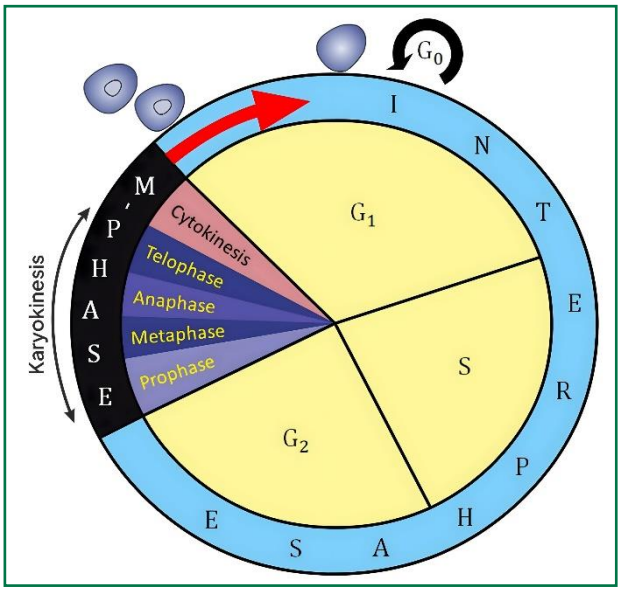


Fig : A diagrammatic view of cell cycle indicating formation of two cells from one cell

- Period of preparation for cell division.
- This is phase between two successive M-phase.
- In interphase cell grows in size and prepares itself for next division. Interphase is **most active phase** of cell cycle.
- It is significant to note that in the 24-hour average duration of cell cycle of a human cell, cell division proper lasts for only about an hour. The interphase lasts more than 95% of the duration of cell cycle.
- A series of metabolic changes occurs during interphase in cell. These changes were not visible under microscope, so some scientist termed interphase as **resting phase**.
- It is the time during which cell is preparing for division by undergoing both cell growth and DNA replication in an orderly manner.
- The interphase is divided into three further phases:
  (i) G_1 phase **(Gap 1)** (ii) S phase **(Synthesis)** (iii) G_2 phase **(Gap 2)**

(i) G_1-phase or Pre DNA-synthesis phase (I^{st} Gap phase)

- G_1 phase corresponds to the **interval between mitosis and initiation of DNA replication.** During G_1 phase the cell is metabolically active and continuously grows but does not replicate its DNA.
- G_1 phase is the period when the cell grows and carries out normal metabolism. Most of the organelle duplication also occurs during this phase.
- During **G_1, cell** rapidly synthesizes different **types of RNA and proteins.** Due to availability of protein, synthesis of new protoplasm takes place in cell and it starts growing in size. Cell grows maximum in G_1 stage.

(ii) S-phase (DNA synthesis phase):

- **Replication of nuclear DNA** and synthesis of **histone protein** takes place in S-phase.
- Replication of **cytoplasmic DNA** may occur in any stage of cell cycle.
- During this time the **amount of DNA per cell doubles.** If the initial amount of DNA is denoted as 2C then it increases to 4C. However, there is **no increase in the chromosome number**; if the cell had diploid or 2n number of chromosomes at G_1, even after S phase the number of chromosomes remains the same, i.e., 2n.
- S-phase marks the phase of DNA replication and chromosome duplication (DNA content in a chromosome become double).
- **In animal cells**, during the S phase, **DNA replication** begins in the nucleus, and the **centriole duplicates** in the cytoplasm.

NCERT Question :

Can there be mitosis without DNA replication in 'S' phase?

Ans.

During mitosis, DNA duplicates in S-phase and this is a very important step. If DNA duplication does not occur in mitosis, there will be a reduction in the number of chromosomes of daughter cells. Thus, mitosis cannot occur without DNA replication.

(iii) G_2 - phase (2nd Gap phase) or Post DNA synthesis phase (Pre-mitosis phase)

- During the G_2 phase, proteins are synthesised in preparation for mitosis while cell growth continues.
- G_2 phase is the **period of cytoplasmic growth**.
- Final preparation of M-phase occurs during this phase. Special materials required for M-phase are synthesized in G_2 phase. **e.g. Tubulin protein**. (Required for formation of spindle fibres). Cell growth continues.

NCERT Question :

Describe the events taking place during interphase.

Ans. Interphase refers to the phase in the cell cycle which prepares the cell and its nucleus for division. Interphase is divided into three sub-phases : G_1 phase, S Phase and G_2 phase.

1. G_1 phase- It is the longest stage of interphase, also called the first growth phase or post-mitotic gap phase. Both the cell and its nucleus grow in size. There is the synthesis of different types of RNA and proteins.
2. S-Phase- In this phase, DNA replication occurs. The content of DNA doubles up, however, the number of chromosomes remains the same. The centrosome, if present begins to divide.
3. G_2 phase- This phase is characterized by increased synthesis of RNA and proteins. The cell organelles undergo multiplication in this phase while the cell grows in size. The G_2 phase is also called as second growth phase or pre-mitotic gap phase.

G_0 PHASE

Some cells in the adult animals do not appear to exhibit division (**e.g.**, heart cells) and many other cells divide only occasionally, as needed to replace cells that have been lost because of injury or cell death. These cells that do not divide further exit G_1 phase to enter an inactive stage called quiescent stage (G_0) of the cell cycle. Cells in this stage remain metabolically active but no longer proliferate unless called on to do so depending on the requirement of the organism.

NCERT Question :

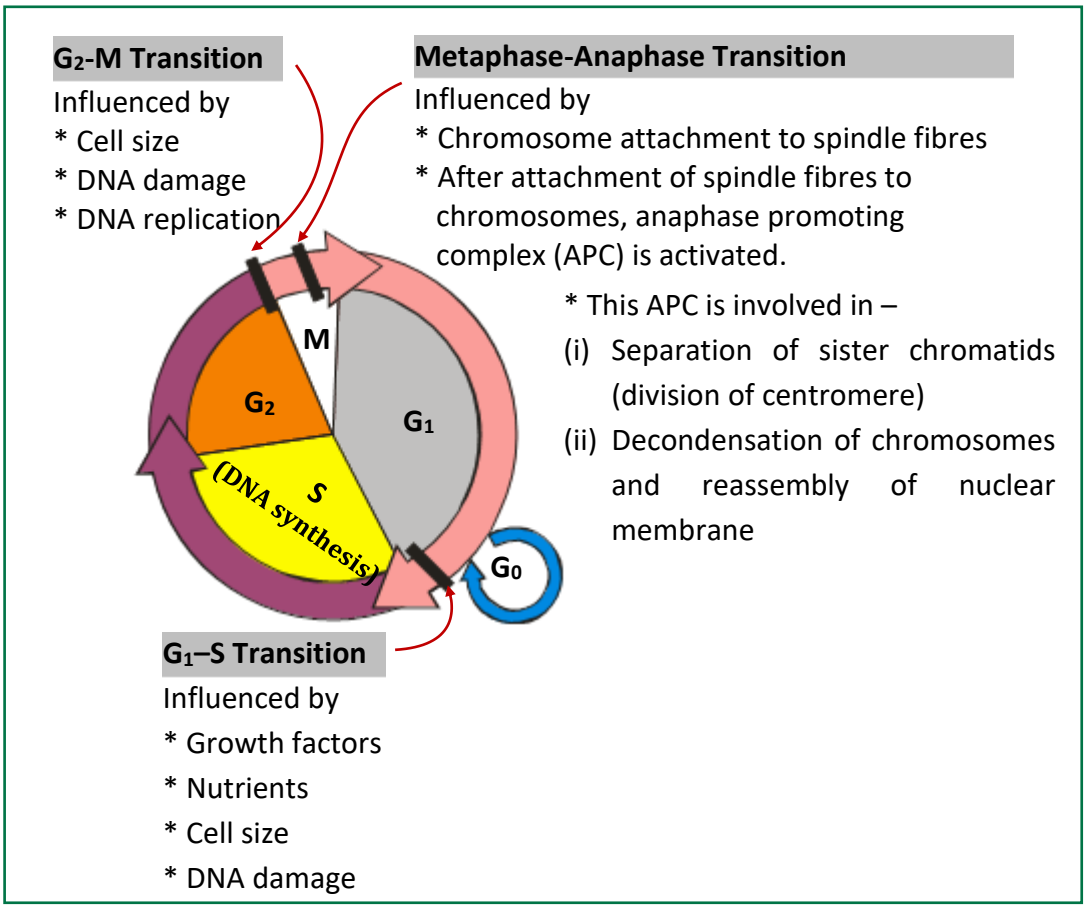
What is the G_0 (quiescent phase) of the cell cycle?

Ans.

It refers to the stage when cell suspends the cell cycle. The cells of this stage are metabolically active and divide only when called on to do so.

Checkpoints of cell cycle :-

- Cell cycle is running by a group of special proteins **"Cyclins and Cdks**. (Nurse, T. Hunt & Hartwell **2001** studied on *Saccharomyces*)
- Kinase is an enzyme that removes a phosphate group from ATP & add to another protein. The kinases involved in the cell cycle are called **Cdks** because they are activated when they combined with key protein called **cyclin**.
- At some check points a kinase enzyme combines with cyclin & this moves the cell cycle forwardly.
- G_2–M transition is triggered by maturation promoting factor (MPF) formed by M-cyclin + CDK.



03. MITOSIS PHASE / M-PHASE / DIVISION PHASE

- **Division phase** or **M-phase** or mitotic phase lasts for only about an hour in the 24-hour duration of cell cycle of a human cell.
- The **M-phase** represents the phase when the **actual cell division** or **mitosis occurs**. In animals, mitotic cell division is restricted or only seen in diploid somatic cell except in some social insects. Against this, the plants can show mitotic division in both haploid and diploid cells.
- This is the **most dramatic period** of the cell cycle, involving a major reorganisation of virtually all components of the cell. Since the number of chromosomes in the parent and progeny cells is the same, it is also called as **equational division**.
- The M-phase **starts with** nuclear division, corresponding to the separation of daughter chromosomes **(Karyokinesis)** and **usually ends with** division of cytoplasm **(cytokinesis)**.
- Though for convenience mitosis has been divided into four stages of nuclear division, it is very essential to understand that cell division is a progressive process and very clear-cut lines cannot be drawn between various stages which are as following –

  (1) Prophase (2) Metaphase (3) Anaphase (4) Telophase

NCERT Question :

Distinguish cytokinesis from karyokinesis.

Ans.

The differences between cytokinesis and karyokinesis are as follows:

Cytokinesis	Karyokinesis
The process of division of cytoplasm is called cytokinesis	The process of division of the nucleus is called karyokinesis
Cytokinesis takes place after karyokinesis	Karyokinesis takes place after interphase.

NCERT Question :

Why is mitosis called equational division?

Ans.

Mitosis is called equational division because daughter cells have same number of chromosomes as compared to parental cells. Similarly, the ploidy of the parental and daughter cells also remains the same in mitosis.

(1) PROPHASE :

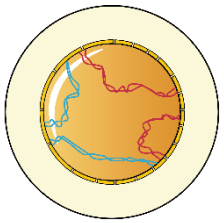


Fig : EARLY PROPHASE

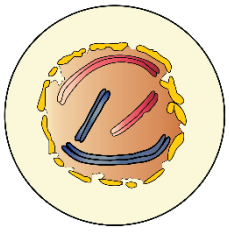


Fig : LATE PROPHASE

- Prophase which is the **first stage of karyokinesis** of mitosis follows the S and G_2 phases of interphase.
- In the **S and G_2 phases** the **new DNA molecules formed** are not distinct but intertwined.
- Prophase is marked by the **initiation of condensation of chromosomal material**. The chromosomal material becomes untangled during the process of chromatin condensation.
- The centrioles (Centrosome), which had undergone duplication during S phase of interphase, now begins to move towards opposite poles of the cell.
- The completion of prophase can thus be marked by the following **characteristic events**:
  1. Chromosomal material condenses to form compact mitotic chromosomes. Chromosomes are seen to be composed of two chromatids attached together at the centromere.
  2. **Centrosome which had undergone duplication during interphase, begins to move towards opposite poles of the cell. Each centrosome radiates out microtubules called asters. The two asters together with spindle fibres forms mitotic apparatus.**
  3. Cell at the end of prophase when viewed under the microscope, do not show **Golgi complexes, endoplasmic reticulum, nucleolus** and **nuclear envelope.**

(2) METAPHASE :

- The **complete disintegration of the nuclear envelope** marks the start of the second phase of mitosis, hence the chromosomes are spread through the cytoplasm of the cell.

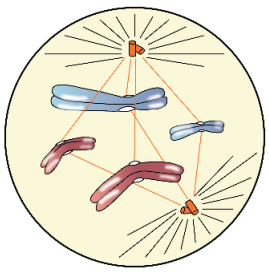


Fig : TRANSITION TO METAPHASE

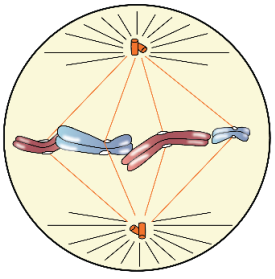


Fig : METAPHASE

- By this stage, **condensation of chromosomes is completed** and they can be observed clearly under the microscope. **This then, is the stage at which morphology of chromosomes is most easily studied.**

- At this stage, metaphase chromosome is made up of two sister chromatids, which are held together by the centromere. Small disc-shaped structures at the surface of the centromeres are called **kinetochores. These structures serve as the sites of attachment of spindle fibres (formed by the microtubules) to the chromosomes that are moved into position at the centre of the cell.**
- Hence, the **metaphase is characterised by** all the chromosomes coming to lie at the equator with one chromatid of each chromosome connected by its kinetochore to spindle fibres from one pole and its sister chromatid connected by its kinetochore to spindle fibres from the opposite pole. The plane of alignment of the chromosomes at metaphase is referred to as the **metaphase plate.**
- Centromere lies at equator and arms of chromosomes remain directed towards poles.
- The key features of metaphase are:
  1. Spindle fibres attach to kinetochores of chromosomes.
  2. Chromosomes are moved to spindle equator and get aligned along metaphase plate through spindle fibres to both poles.

NCERT Question :

Name the stage of cell cycle at which one of the following events occur:

Chromosomes are moved to spindle equator.

Ans. During metaphase, the chromosomes move to the spindle equator and align themselves to form an equatorial plate or metaphasic plate.

(3) ANAPHASE :

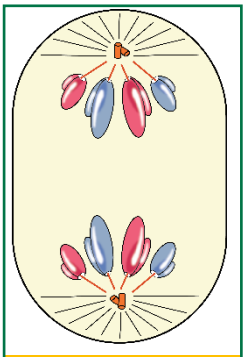


Fig : ANAPHASE

- At the onset of anaphase, each chromosome arranged at the metaphase plate is split simultaneously and the two daughter chromatids, now referred to as daughter chromosomes of the future daughter nuclei, begin their migration towards the two opposite poles.
- As each chromosome moves away from the equatorial plate, the centromere of each chromosome remains directed towards the pole and hence at the leading edge, with the arms of the chromosome trailing behind
- **Number of chromosomes become double** in cell.
- **The two new daughter chromosomes begin moving toward opposite ends of the cell as their spindle fibres shorten.**

- Anaphase stage is characterised by the following **key events**:
  1. Centromeres split and chromatids separate.
  2. Chromatids (now referred as chromosomes) move to opposite poles.

NCERT Question :

Name the stage of cell cycle at which one of the following events occur:

Centromere splits and chromatids separate.

Ans. During anaphase, the centromere splits, and sister chromatids are separated. These chromatids after separation move to the opposite poles and form daughter chromosomes.

(4) TELOPHASE (REVERSE PROPHASE) :

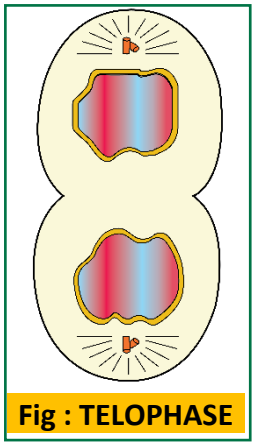


Fig : TELOPHASE

- At the beginning of the final stage of karyokinesis, i.e., telophase, the chromosomes that have reached their respective poles decondense and lose their individuality.
- The individual chromosomes can no longer be seen and chromatin material tends to collect at each of the two poles.
- This is the stage which shows the following **key events**:
  1. Chromosomes cluster at opposite spindle poles and their identity is lost as discrete elements.
  2. Nuclear envelope develops around the chromosome clusters at each pole forming two daughter nuclei.
  3. Nucleolus, Golgi complex and ER reform.

CYTOKINESIS :

- Mitosis accomplishes not only the segregation of duplicated chromosome into daughter nuclei (Karyokinesis) but the cell itself is divided into two daughter cells by the separation of cytoplasm called cytokinesis at the end of which cell division gets completed.
- In an **animal cell**, this is achieved by the appearance of a furrow in the plasma membrane. **At the periphery** of the equator a contractile ring is formed that is made up of actin and myosin protein. Due to interaction between **actin and myosin ring** contract, thus a furrow forms from outside to inside in cell. The furrow gradually deepens and ultimately joins in the centre dividing the cell cytoplasm into two.
- In animals' cytokinesis occurs in **centripetal order.**

- **Plant cells** however, are enclosed by a relatively inextensible cell wall, therefore they undergo cytokinesis by a different mechanism.
- In plant cells, wall formation starts in the centre of the cell and grows outward to meet the existing lateral walls. The formation of the new cell wall begins with the formation of a simple precursor, called the **cell-plate** that represents the **middle lamella** between the walls of two adjacent cells. At the time of cytoplasmic division, organelles like mitochondria and plastids get distributed between the two daughter cells.

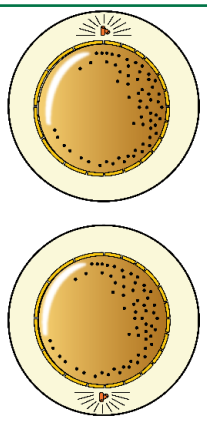


Fig : Cytokinesis

- Many Golgi vesicles arrange themselves on equator. Membrane of Golgi vesicles fuse to form a plate like structure called **cell plate**. Golgi vesicles secret calcium and magnesium pectate. Further cell plate is modified into middle lamella.
- In plants, cytokinesis occurs in **centrifugal order** (cell plate formation is from centre to periphery).
- In some organisms **karyokinesis is not followed by cytokinesis as a result of which multinucleate condition arises leading to the formation of syncytium (*e.g.*, liquid endosperm in coconut).**

NCERT Question :

How does cytokinesis in plant cells differ from that in animal cells?

Ans.

Cytokinesis in plants	Cytokinesis in animals
It occurs by cell plate method	It takes place by cleavage method
Cell plate grows centrifugally i.e. inner to outer	Cleavage takes place centripetally i.e. outer to inner

NCERT Question :

Can there be DNA replication without cell division?

Ans.

Yes, DNA replication can occur without being followed by cell division. For example, formation of syncytium in coconut endosperm forming a multinucleated condition.

04. SIGNIFICANCE OF MITOSIS

- Mitosis or the equational division is **usually restricted** to the **diploid cells only**. However, **in some lower plants** and **in some social insects** haploid cells also divide by mitosis.
- Mitosis usually results in the production of diploid daughter cells with identical genetic complement.
- The **growth of multicellular organisms** is due to mitosis. Cell growth results in disturbing the ratio between the nucleus and the cytoplasm. It therefore becomes essential for the cell to divide to restore the nucleo-cytoplasmic ratio.
- A very significant contribution of mitosis is **cell repair**. The cells of the upper layer of the epidermis, cells of the lining of the gut, and blood cells are being constantly replaced. Mitotic divisions in the meristematic tissues – the apical and the lateral cambium, result in a continuous growth of plants throughout their life.
- **Development of an organism** occurs by mitosis. Every organism starts its life from a single cell i.e. zygote. Repeated mitosis in zygote leads to the formation of the whole body.

BEGINNER'S BOX-1

INTRODUCTION, CELL CYCLE, MITOSIS PHASE (M-PHASE), SIGNIFICANCE OF MITOSIS, MODIFICATIONS

1. First gap phase in cell cycle is :-
(1) interval between mitotic phase and initiation of DNA replication phase
(2) interval between DNA replication phase and DNA separation phase
(3) interval between karyokinesis and cytokinesis
(4) interval between DNA replication phase and second gap phase

BCD163

2. The two chromatids of a metaphase chromosome represent:-
(1) replicated DNA to be separated at anaphase
(2) replicated DNA to be separated at prophase
(3) replicated DNA to be separated at telophase
(4) replicated DNA to be separated at interphase

BCD164

3. A cell that is entering the M-phase of cell cycle is :-
(1) always haploid and with duplicated chromosomes
(2) either haploid or diploid and with duplicated chromosomes
(3) either haploid or diploid and with duplicated or unduplicated chromosomes
(4) always diploid and with unduplicated chromosomes

BCD165

4. A cell examined during prophase of cell cycle contained 100 units of DNA and 50 chromosomes. What would be the number of DNA and chromosomes in anaphase of this cell cycle?

(1) 200 DNA & 100 chromosomes (2) 100 DNA & 50 chromosomes

(3) 100 DNA & 100 chromosomes (4) 50 DNA & 25 chromosomes

BCD166

5. Which type of chromosome is present in the prophase of cell cycle?

(1) 2 chromatid (2) 1 chromatid (3) 4 chromatid (4) 8 chromatid

BCD167

6. Which of the following events takes place during cell cycle?

(1) Cell growth (2) Cell division (3) Cell death (4) Both (1) and (2)

BCD168

7. Cell cycle involves which type of cell division?

(1) Meiosis (2) Mitosis (3) Meiosis-I (4) Meiosis-II

BCD169

8. Mitosis occurs to –

(1) Disturb the KI (2) Restore the KI

(3) Decrease the KI (4) Both (1) and (3)

BCD170

9. In some organisms karyokinesis is not followed by cytokinesis leading to formation of _____.

(1) Liquid endosperm in coconut (2) Solid Endosperm in coconut

(3) Enucleated condition (4) Syncytium

BCD171

10. Which of the following is not a significance of mitosis?

(1) Restoration of nucleo-cytoplasmic ratio

(2) Development of an organism

(3) Bringing genetic variations

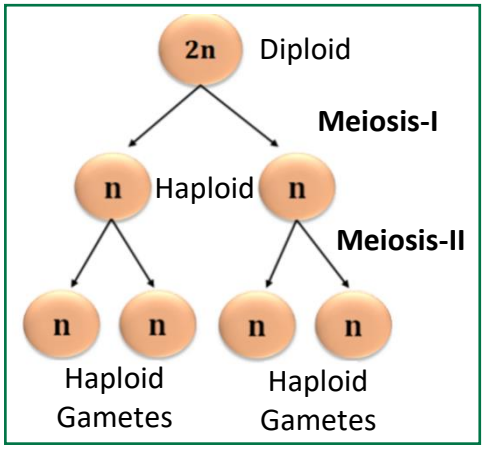
(4) Replacement of blood cells

BCD172

05. MEIOSIS

- The production of offspring by sexual reproduction includes the fusion of two gametes, each with a complete haploid set of chromosomes. Gametes are formed from specialised diploid cells.
- The specialised kind of cell division that reduces the chromosome number by half results in the production of haploid daughter cells. This kind of division is called **meiosis**.

- Meiosis ensures the production of haploid phase in the life cycle of sexually reproducing organisms whereas fertilisation restores the diploid phase. Meiosis occurs during gametogenesis, leads to the formation of haploid gametes.



KEY FEATURES OF MEIOSIS

- Meiosis involves two sequential cycles of nuclear and cell division called **meiosis I** and **meiosis II** but only a single cycle of DNA replication.

MEIOSIS-I :

- Heterotypic division or **reduction division**. It leads to reduction in chromosome numbers. **Division of chromosome does not occur** in meiosis-I, only **segregation of homologous chromosomes** takes place.
- Meiosis I is initiated **after** the parental chromatids have replicated to produce identical sister chromatids at the S phase.
- Meiosis I involve **pairing of homologous chromosomes** and **recombination** between non sister chromatids of homologous chromosome.

MEIOSIS-II :

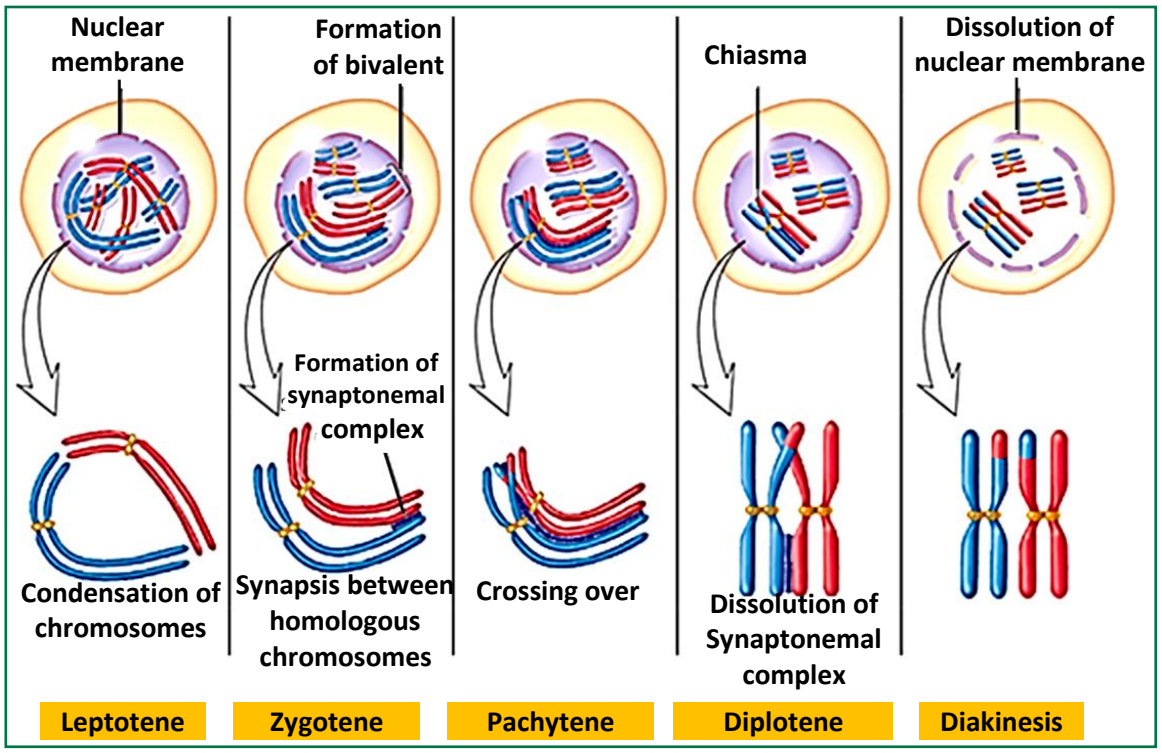
- This is a homotypic division or equational division. It does not lead to any change in chromosome number.
- Division of chromosome or centromere occurs during meiosis II.
- **Four haploid cells** are formed at the end of **meiosis II**. All the four daughter cells produced by meiosis are genetically different from each other and also differ from the mother cell.
- **In meiosis, division of nucleus takes place twice but division of chromosome occurs only once in meiosis-II.**
- **Interphase is same as for mitosis**.
- Meiotic events can be grouped under the following phases:

Meiosis I	Meiosis II
Prophase I	Prophase II
Metaphase I	Metaphase II
Anaphase I	Anaphase II
Telophase I	Telophase II

Stages of Meiosis-I :

Prophase-I :

- Typically, **longer** and **more complex** when compared to prophase of mitosis. Prophase-I is classified in five substages based on chromosomal behaviour.



(a) Leptotene –

- Chromatin threads condense to form chromosomes. Chromosomes are **longest & thinnest.**
- Chromosomes become gradually visible under the light microscope.
- All the chromosomes in nucleus remain directed towards centrioles, so group of chromosomes in nucleus appears like a bouquet. **(Bouquet stage)**

(b) Zygotene or Synaptotene –

- Zygotene is characterized by pairing of homologous chromosomes **(Synapsis)**. A structure develops in between homologous chromosomes, which is termed as ***synaptonemal complex***.
- Pairs of homologous chromosomes are called **Bivalents** or **tetrads**. However, these are more clearly visible at next stage (pachytene).
- The 1st two stages of prophase I are relatively short lived compared to the pachytene.

NCERT Question :

Name the stage of cell cycle at which one of the following events occur:

Pairing between homologous chromosomes takes place.

Ans. The pairing between homologous chromosomes takes place during zygotene of prophase I of meiosis I. This process is called as synapsis.

(c) Pachytene –

- During this stage, the four chromatids of each bivalent chromosome become distinct and clearly appeared as tetrad.
- *Recombination nodules* between non-sister chromatids of homologous pair develop and these non-sister chromatids exchange their parts i.e. **crossing over**.
- Crossing over leads to recombination of genetic material on the two chromosomes. Crossing over is an enzyme mediated process and the enzyme involved is called **recombinase**.
- Recombination between homologous chromosomes is completed by the end of pachytene, leaving the chromosomes linked at the sites of crossing over.

NCERT Question :

Name the stage of cell cycle at which one of the following events occur:

Crossing over between homologous chromosomes takes place.

Ans. Crossing over between homologous chromosomes takes place during pachytene of prophase I of meiosis I.

(d) Diplotene –

- The beginning of diplotene is recognised by dissolution of synaptonemal complex. Homologous chromosomes start repulsing each other so **X-shape** structures appear, called **chiasmata.**
- **Diplotene** may last long up to months or years in oocytes of some vertebrates.

(e) Diakinesis –

- It is final stage of meiotic prophase I. Marked by **terminalisation** of chiasmata (Chiasmata open in zip like manner).
- **Chromosome are fully condensed** and meiotic spindle is assembled to prepare the homologous chromosome for separation. Centrioles move towards the opposite poles.
- By the end of diakinesis nucleolus disappear and the nuclear envelop also breaks down.
- Diakinesis represents **transition to metaphase.**

NCERT Question :

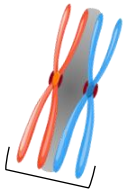
Describe the following:

(a) synapsis (b) bivalent (c) chiasmata

Draw a diagram to illustrate your answer.

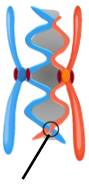
Ans.

(a) Synapsis- The process of the pairing of homologous chromosomes during the zygotene stage of prophase I of "meiosis I" is called synapsis. During synapse, a synaptonemal complex is formed by the homologous chromosome which is referred to as a bivalent or a tetrad.



(b) Bivalent- It refers to the structure formed by a pair of the synapsed homologous chromosome.

Bivalent



(c) Chiasmata- These are points of attachment between homologous chromosomes during their separation in diplotene of the prophase I stage of meiosis. Chiasmata are initially formed in the regions of crossing over between non-sister chromatids but later on, tend to shift sideways.

Chiasmata

Metaphase-I :

- Bivalents arrange on equator (congression) of cell to form metaphase plate. The microtubules (spindle fibres) from the opposite poles of the spindle attach to the pair of homologous chromosomes with one kinetochore of each chromosome.

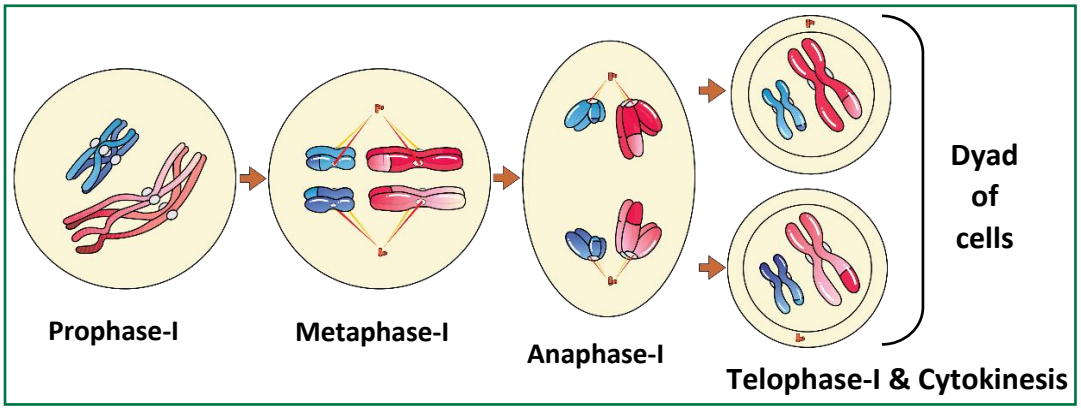
Anaphase-I :

- Due to shortening of kinetochore/chromosomal fibres homologous chromosomes segregate from each other and move towards the opposite poles. Sister chromatids remain associated at their centromeres (i.e. chromosomes remain in double chromatid stage)
- Anaphase I is characterised by segregation of chromosomes. **Division of centromere is absent.**

Telophase-I :

- The nuclear membrane and nucleolus reappear. Although in many case the chromosomes do undergo some dispersion, but they do not reach the extremely extended state of the interphase nucleus.

- Cytokinesis follows telophase-I and a diploid (2n) cell divides into two haploid (n) daughter cells. This is called as dyad of cells.



Interkinesis :

- Gap between meiosis I and meiosis II is called Interkinesis. Preparations of meiosis II occur during interkinesis. **It is like interphase of mitosis but replication of DNA is absent in interkinesis.**
- Interkinesis is generally short lived. Interkinesis is followed by prophase-II, a much simpler prophase than prophase-I.

Stages of Meiosis-II :

Prophase-II :

- Meiosis II is initiated immediately after cytokinesis, usually before the chromosomes have fully elongated. In contrast to meiosis I, meiosis II resembles a normal mitosis.
- The nuclear membrane disappears by the end of prophase II. The chromosomes again become compact.

Metaphase-II:

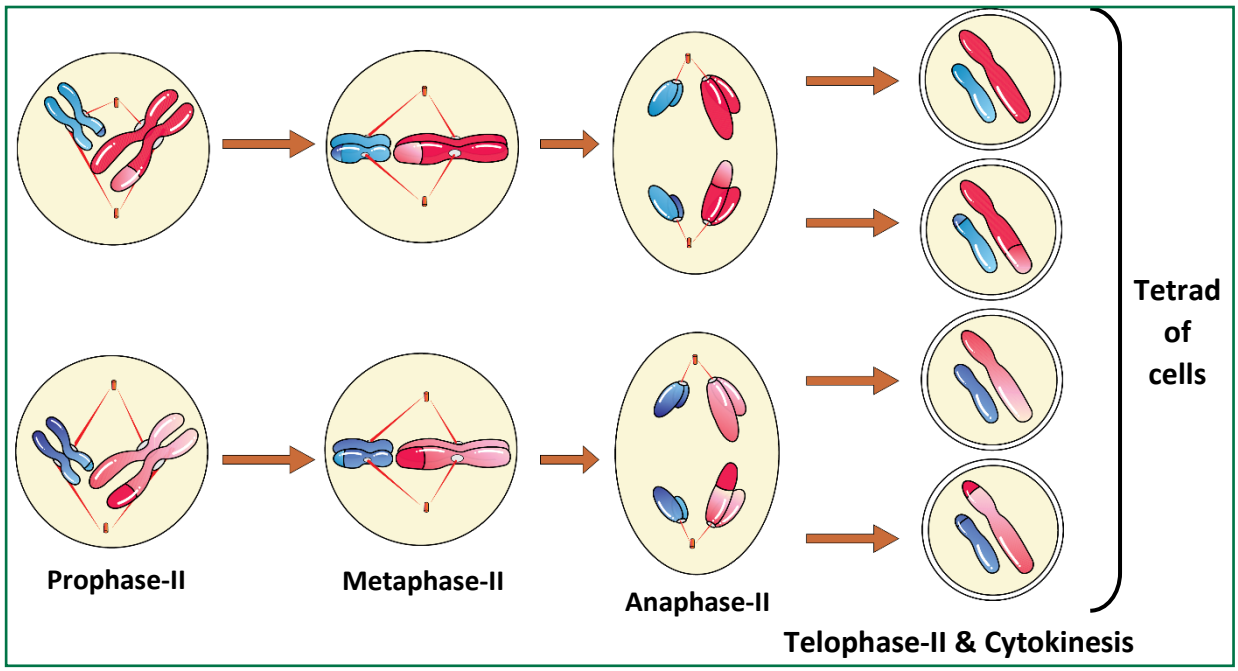
- At this stage the chromosomes align at the equator and the microtubules from opposite poles of the spindle get attached to the kinetochores of sister chromatids.

Anaphase-II:

- It begins with the simultaneous **splitting of the centromere of each chromosome** (which was holding the sister chromatids together), allowing them to move toward opposite poles of the cell by microtubules attached to kinetochores.

Telophase-II:

- Meiosis ends with telophase II, in which the two groups of chromosomes once again get enclosed by a nuclear envelope; cytokinesis follows resulting in the formation of tetrad of cells i.e., four haploid daughter cells.



NCERT Question :

Find examples where the four daughter cells from meiosis are equal in size and where they are found unequal in size.

Ans.

Meiosis is the reductional division that leads to the formation of four daughter cells which have half the number of chromosomes than the parent cell. In males all the four daughter cells called sperms formed are equal in size while in females the daughter cells are unequal in size.

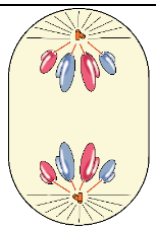
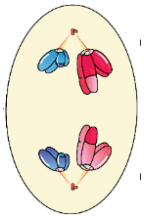
06. SIGNIFICANCE OF MEIOSIS

- Meiosis is the mechanism by which conservation of specific chromosome number of each species is achieved across generations in sexually reproducing organisms, even though the process **(per se paradoxically)** results in reduction of chromosome number by half.
- It also increases the genetic variability in the population of organisms from one generation to the next. Variations are very important for the process of evolution.

NCERT Question :

Distinguish anaphase of mitosis from anaphase I of meiosis.

Ans.

Anaphase of mitosis	Anaphase I of meiosis
Anaphase of mitosis involves the splitting of each chromosome at centromere into two sister chromatids which start moving towards the opposite poles and form daughter chromosomes.	Anaphase I of meiosis I involves the separation of homologous chromosomes, while the sister chromatids remain attached to their centromere.
	

NCERT Question :

List the main differences between mitosis and meiosis.

Ans.

Mitosis	Meiosis
It takes place in somatic cells.	It takes place in germ cells.
The cells undergoing mitosis can be diploid or haploid.	The cells that undergo meiosis cannot be haploid.
It involves a single division producing two daughter cells.	It involves two sequential divisions that give rise to four daughter cells.
The daughter cells formed after mitosis are exactly similar to their parent cell.	The daughter cells formed after meiosis are neither similar to the parent one nor to one another.
The number of chromosomes remains the same after mitosis.	The number of chromosomes is reduced to half after meiosis.
Mitosis helps in the multiplication of cells, growth and repair.	Meiosis is involved in the formation of gametes.

NCERT Question :

What is the significance of meiosis?

Ans. (1) Meiosis form gametes that are required for sexual reproduction

(2) Meiosis conserves the fixed number of chromosomes in sexually reproducing organisms across generations.

(3) Meiosis introduces a new combination of variations.

(4) Variations are important for the process of evolution.

NCERT Question :

Discuss with your teacher about

(i) haploid insects and lower plants where cell-division occurs, and

(ii) some haploid cells in higher plants where cell-division does not occur.

Ans.

(i) In some lower plants and haploid insects such as drones of a honey bee where gametes are formed by mitosis rather than meiosis.

(ii) Synergids and antipodals cells of embryo sac and vegetative cell of pollen grains are haploid cells in higher plants where cell division does not occur.

NCERT Question :

Analyse the events during every stage of cell cycle and notice how the following two parameters change:

(i) number of chromosomes (N) per cell

(ii) amount of DNA content (C) per cell

Ans.

(i) The number of chromosomes (N) per cell changes during the anaphase I stage of meiosis I. During this stage, the homologous chromosomes get separated and start moving towards the opposite poles. Thus, the bivalents get divided. This leads to a reduction of the number of chromosomes to half in daughter cells.

(ii) Amount of DNA gets double during S-phase of interphase and remains same till metaphase-I stage. While it gets reduced to half during anaphase-I of meiosis-I and also during the anaphase-II of meiosis-II.

BEGINNER'S BOX-2

MEIOSIS, SIGNIFICANCE OF MEIOSIS, DIFFERENCES BETWEEN MITOSIS AND MEIOSIS

1. Synaptonemal complex is a nucleoprotein structure. It is visible or found from-

(1) zygotene to pachytene (2) leptotene to diplotene

(3) zygotene to metaphase (4) pachytene to diplotene

BCD173

2. Which one of the following is correctly matched?

(1) Leptotene - formation of bivalents (2) Diplotene - chiasmata appear

(3) Pachytene - chiasmata terminalisation (4) Zygotene - formation of bouquet

BCD174

3. In which stage of meiosis, chromosomes are thin, long, thread like?

(1) Zygotene (2) Leptotene (3) Pachytene (4) Diakinesis

BCD175

4. Meiosis involves-

(1) one nuclear division and one chromosome division

(2) two nuclear divisions and one chromosome division

(3) one nuclear division and two chromosome divisions

(4) two nuclear divisions and two chromosome divisions

BCD176

5. In meiosis, centromeres of chromosomes divide during-

(1) anaphase of meiosis-II (2) metaphase of meiosis-I

(3) anaphase of meiosis-I (4) prophase of meiosis-II

BCD177

6. Which of the following division results in reduction of number of chromosomes?

(1) Mitosis (2) Meiosis-I (3) Meiosis-II (4) Both (1) and (2)

BCD178

7. Formation of synaptonemal complex occurs during which stage?

(1) Diplotene (2) Pachytene (3) Zygotene (4) Leptotene

BCD179

8. Recombination occurs during which stage?

(1) Diakinesis (2) Pachytene (3) Meiosis-II (4) Synaptotene

BCD180

9. Interkinesis is followed by -

(1) Prophase-I (2) Telophase-I (3) Telophase-II (4) Prophase-II

BCD181

10. The gap between meiosis-I and meiosis-II is called as -

(1) Interphase (2) Interkinesis (3) Crossing over (4) Cytokinesis

BCD182

BEGINNER'S BOX ANSWERS KEY

BEGINNER'S BOX-1	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	1	1	2	3	1	4	2	2	4	3

BEGINNER'S BOX-2	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	1	2	2	2	1	2	3	2	4	2

ESSENCE

M-Phase
- Actual phase when division occurs
- Most dramatic period
- Reorganisation of virtually all components of the cell
- Starts with karyokinesis and ends with cytokinesis

Karyokinesis
- Division of Nucleus
- Divided into Prophase, Metaphase, Anaphase, Telophase

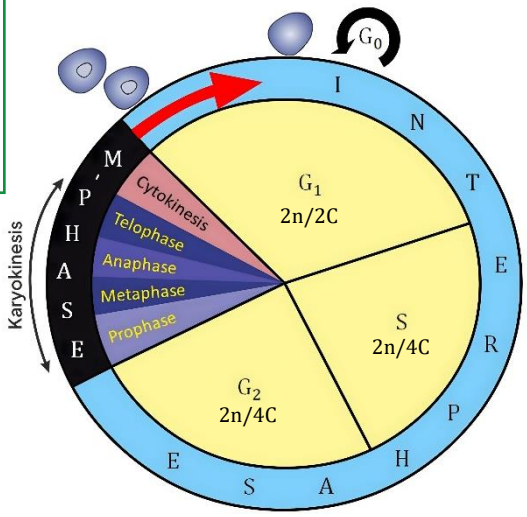
Cytokinesis
- Division of Cytoplasm
- Furrow method [centripetal] in animal cell
- Cell plate method [centrifugal] in plant cell

Telophase (T)
- ER, Golgi apparatus, Nucleolus, Nuclear membrane reform
- Chromosomes decondense and lose their individuality

Quiescent stage (G_0 phase)
- Cells remain metabolically active. but no longer proliferate until called on to do so.
- Heart cells remain in permanent G_0.
- Cell exit G_1 phase.

Interphase
- Phase between two successive M-phase
- More than 95% duration of cell Cycle
- Preparation for division/M-phase

Anaphase (A)
- Centromeres split
- Sister chromatids separate
- Number of chromosomes become double
- Daughter chromosomes move towards opposite poles



G_1 phase
- Interval between mitosis and initiation of DNA replication.
- Cell is metabolically active and continuously grows
- Most of the organelles duplicates

Metaphase (M)
- Condensation of chromosome completed.
- Suitable for study of morphology of chromosome
- Spindle fibres attach with Kinetochore
- Chromosomes lie at the equator

S phase
- Replication of DNA
- Centriole duplication (In cytoplasm of animal cell)
- Synthesis of histone proteins
- Chromosome number remains same but DNA content becomes double

Prophase (P)
- Condensation of chromatin material starts
- Replicated centrioles start to move towards opposite poles.
- Initiation of the assembly of spindle fibres
- At the end Golgi apparatus, ER, nucleolus and nuclear membrane disappeared

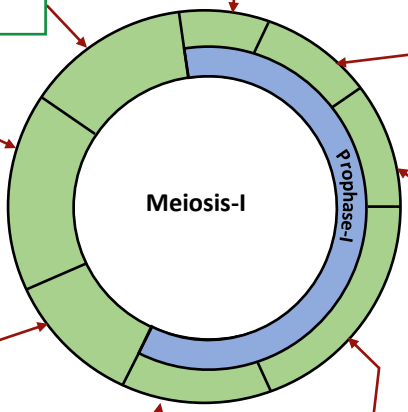
G_2 phase
- Protein formed for formation of spindle fibres
- Cell growth continues
- Pre-mitotic phase

Telophase-I
- Nuclear membrane and nucleolus reappear
- Chromosomes decondense but do not reach the extremely extended state of the interphase nucleus

Leptotene
- 'Bouquet stage'
- Chromosome become visible under light microscope
- Compaction of chromosome starts

Zygotene
- Formation of synaptonemal complex
- Pairing of homologous chromosomes
- Pairing is called synapsis
- Pair of homologous chromosomes is called bivalent/tetrad

Anaphase-I
- Homologous chromosomes separated
- Sister chromatids remain associated



Metaphase-I
- Bivalent chromosomes align on equatorial plate
- Spindle fibres attach to the pair of homologous chromosomes

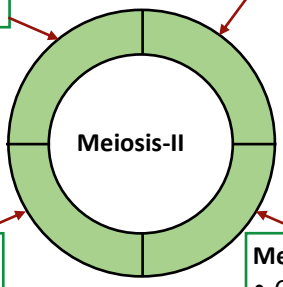
Pachytene
- Tetrads are clearly visible
- Formation of recombination nodules
- Crossing over occurs between non-sister chromatids of the homologous chromosomes
- Recombinase enzyme involved in crossing over
- At the end, recombination completed, leaving the chromosomes linked at the sites of crossing over

Diakinesis
- Marked by terminalisation of chiasmata
- Chromosomes are fully condensed
- Spindle is assembled to prepare the homologous chromosomes for separation
- Nucleolus disappear and nuclear envelope also breaks down

Diplotene
- Dissolution of synaptonemal complex
- Homologous chromosomes separate from each other except at the sites of cross overs
- X-shaped structures called chiasmata are visible
- This phase can lasts for month or years in some vertebrate's oocytes.

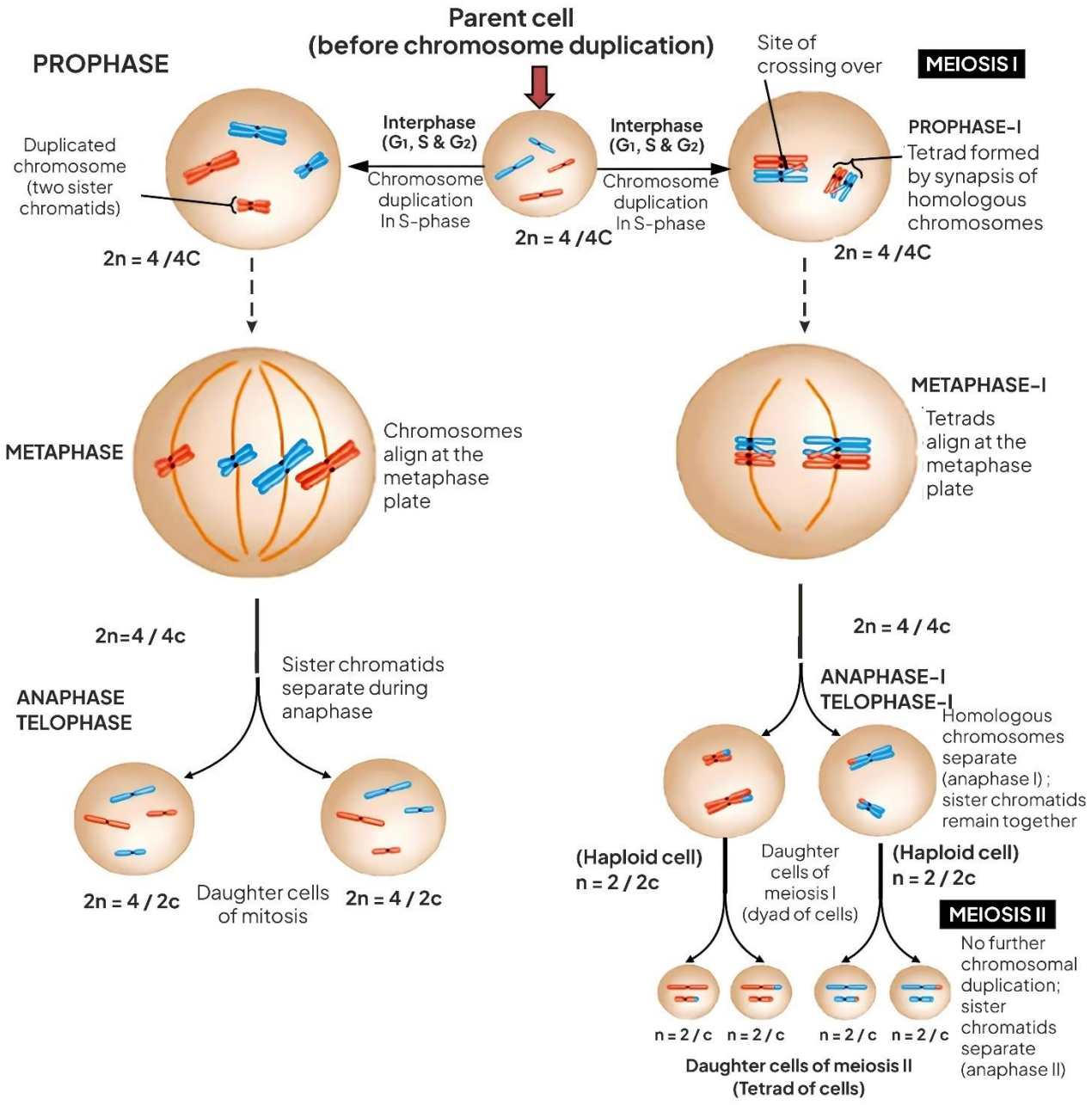
Telophase-II
- Meiosis ends with telophase-II
- Two groups of chromosomes once again get enclosed by a nuclear envelope.

Prophase-II
- The nuclear membrane disappears
- The chromosomes again become compact.



Anaphase-II
- Begins with the simultaneous splitting of centromere of each chromosome allowing daughter chromosomes to move towards opposite poles of the cells.

Metaphase-II
- Chromosomes align at the equator
- The microtubules from opposite poles of the spindle get attached to the kinetochore of sister chromatids.


Parent cell
(before chromosome duplication)
PROPHASE
Duplicated chromosome (two sister chromatids)
2n = 4 /4C
Interphase (G1, S & G2)
Chromosome duplication In S-phase
2n = 4 /4C
Interphase (G1, S & G2)
Chromosome duplication In S-phase
Site of crossing over
MEIOSIS I
PROPHASE-I
Tetrad formed by synapsis of homologous chromosomes
2n = 4 /4C
METAPHASE
Chromosomes align at the metaphase plate
METAPHASE-I
Tetrads align at the metaphase plate
2n=4 / 4c
ANAPHASE
TELOPHASE
Sister chromatids separate during anaphase
2n = 4 / 2c
Daughter cells of mitosis
2n = 4 / 2c
2n = 4 / 4c
ANAPHASE-I
TELOPHASE-I
Homologous chromosomes separate (anaphase I) ; sister chromatids remain together
(Haploid cell)
n = 2 / 2c
Daughter cells of meiosis I (dyad of cells)
(Haploid cell)
n = 2 / 2c
MEIOSIS II
No further chromosomal duplication; sister chromatids separate (anaphase II)
n = 2 / c
n = 2 / c
n = 2 / c
n = 2 / c
Daughter cells of meiosis II
(Tetrad of cells)

NCERT SUMMARY

According to the cell theory, cells arise from preexisting cells. The process by which this occurs is called cell division. Any sexually reproducing organism starts its life cycle from a single-celled zygote. Cell division does not stop with the formation of the mature organism but continues throughout its life cycle. The stages through which a cell passes from one division to the next is called the cell cycle. Cell cycle is divided into two phases called (i) Interphase – a period of preparation for cell division, and (ii) Mitosis (M phase) – the actual period of cell division. Interphase is further subdivided into G1, S and G2. G1 phase is the period when the cell grows and carries out normal metabolism. Most of the organelle duplication also occurs during this phase. S phase marks the phase of DNA replication and chromosome duplication. G2 phase is the period of cytoplasmic growth. Mitosis is also divided into four stages namely prophase, metaphase, anaphase and telophase. Chromosome condensation occurs during prophase. Simultaneously, the centrioles move to the opposite poles. The nuclear envelope and the nucleolus disappear and the spindle fibres start appearing. Metaphase is marked by the alignment of chromosomes at the equatorial plate. During anaphase the centromeres divide and the chromatids start moving towards the two opposite poles. Once the chromatids reach the two poles, the chromosomal elongation starts, nucleolus and the nuclear membrane reappear. This stage is called the telophase. Nuclear division is then followed by the cytoplasmic division and is called cytokinesis. Mitosis thus, is the equational division in which the chromosome number of the parent is conserved in the daughter cell.

In contrast to mitosis, meiosis occurs in the diploid cells, which are destined to form gametes. It is called the reduction division since it reduces the chromosome number by half while making the gametes. In sexual reproduction when the two gametes fuse the chromosome number is restored to the value in the parent. Meiosis is divided into two phases – meiosis I and meiosis II. In the first meiotic division the homologous chromosomes pair to form bivalents, and undergo crossing over. Meiosis I has a long prophase, which is divided further into five phases. These are leptotene, zygotene, pachytene, diplotene and diakinesis. During metaphase I the bivalents arrange on the equatorial plate. This is followed by anaphase I in which homologous chromosomes move to the opposite poles with both their chromatids. Each pole receives half the chromosome number of the parent cell. In telophase I, the nuclear membrane and nucleolus reappear. Meiosis II is similar to mitosis. During anaphase II the sister chromatids separate. Thus at the end of meiosis four haploid cells are formed.